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CURRENT PERFORMANCE OF THE NASA BIOMASS PRODUCTION CHAMBER

by

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SUMMARY:

NASA's Biomass Production Chamber (BPC) is the main component of the Controlled Ecological Life Support System (CELSS). It is a 7.5m by 3.7m cylindrical chamber in which plants are grown hydroponically. The chamber is sealed and nutrient solution and atmosphere are recycled. Several tests have been performed to measure the performance of the chamber. Results of these tests, along with a description of the general operating characteristics, are presented.

KEYWORDS:

Controlled environment, CELSS, growth chambers, recycling, space program.

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Introduction

Human exposure to space has been limited to short duration missions with all necessary supplies taken or received from Earth. In order to make long duration missions feasible, all consumables necessary for life support will have to be recycled as much as possible. With that idea, NASA began research in 1978 into controlled ecological life support systems (CELSS). The main goal was to combine biological and physicochemical systems to produce food, breathing air and potable water by recycling waste in a stable, reliable manner (Averner, 1989).

In 1985, NASA personnel at Kennedy Space Center proposed the development of a CELSS Breadboard to test and demonstrate bioregenerative components. That same year work began on a bioregenerative life support system, the CELSS Breadboard Project, to provide a test bed for large scale demonstration of current CELSS research. Since green plants are central to CO_2 removal and O_2 production, potable water generation and food production, the first component in the CELSS Breadboard Project was the Biomass Production Chamber (BPC). In this way, the current state of controlled environment plant production could be duplicated and studied. Various options for growing plants could be tried, helping to identify the "best set" for a given senario. Also, by growing plants in closed environments, the atmospheric contaminants produced could be determined (Prince and Knott, 1989).

The BPC was originally used for low pressure testing on Mercury space capsules. It is 7.5m high and 3.7m in diameter. Originally, the chamber was physically (but not atmospherically) separated by the addition of a floor. Recently, though, the floor seams were welded shut to create two separate chambers. Efforts are still ongoing to completely quantify the separation of the two part chamber. This leaves an upper and a lower level, each with two shelves for growing plants. With the addition of fans and air ducts for the upper and lower levels, total chamber volume is approximately $113m^3$, with approximately one half of the total volume for each level. Figure 1 shows the outside of the chamber. Plants grow hydroponically in trapezoidal-shaped trays shaped to fit the annular configuration. There are 16 trays per shelf with each shelf having its own supply of nutrients. Total hydroponic growing area of the trays is $16m^2$, and if the area between the trays is included the area under the crop canopy is $20m^2$. Above each growing shelf are two lamp banks made up of eight lamp canopies. Each lamp canopy contains three 400W high intensity discharge (HID) lamps. These lamp canopies have high pressure sodium (HPS) lamps and ballasts, but metal halide (MH) lamps designed to operate on HPS ballasts have also been used. Individual banks of lights can be dimmed to provide varying amounts of photosynthetically active radiation (PAR) ranging from 200 to $700\mu moles/m^2/s$ PPF. Each lamp has the plumbing all increase the leak rate. The most recent change has been the addition of a pressure control system. This consists of a 576L compressed air tank and a 7.5kW compressor to either add or remove chamber air as the chamber pressure moves outside of a preset range. Use of this system has helped remove pressure transients greater than 50pa caused by the change from one temperature set point to another. Small pressure fluctutations caused by the flow of hot and chilled water in the heating and cooling coils is not affected.

Condensate Recovery System - In order to track water usage and to eventually recycle water used, condensation from the cooling coils is collected. Originally, 115L stainless steel collection tanks beneath each air duct were used. The water level was recorded manually and makeup water was added from the facility deionized water supply. To hold the condensate for use, two storage tanks of 300L each were added and the condensate was automatically pumped from the collection tanks to the storage tanks. The stainless steel tanks were replaced by smaller PVC tanks of 2L each, giving the system better volumetric sensitivity and its current configuration. Pumps to move the condensate to the storage tanks are actuated by liquid level switches after a constant volume of 1.5L is collected. Once the condensate is pumped to the storage tanks, it is automatically circulated through deionizing and filtering columns to remove any particulate matter. There are two deionizing columns (one is a backup) and a 0.2 micron filter column for each condensate storage tank. From the condensate storage tanks, water can be either pumped to the nutrient tanks as makeup water, or be drained from the system.

Nutrient Delivery System (NDS) - The nutrient delivery system has undergone the most change of any of the original systems. Originally, nutrients were kept in tanks inside the BPC. Nutrient and pH balance were manually controlled. As construction inside and outside the BPC was completed, the tanks were moved outside and plumbed into a complete system. Each growing level has its own tank of nutrients and is isolated from the other levels. The nutrients are circulated by a 0.5kW pump with an identical backup pump. Flow is controlled by manual ball valves located throughout the plumbing. The most recent change has been the method of controlling nutrient temperature. Originally, water from a 15kW chiller was circulated through a jacket surrounding each NDS tank. However, the tank material would not allow sufficient heat transfer to control the temperature. Nutrient temperature is now controlled by circulating chilled water through a stainless steel coil in each tank.

Nutrient liquid level, electrical conductivity (EC) and pH are automatically controlled. Each level is controlled independently of the other three levels. Makeup water for a nutrient tank comes from the condensate recovery system (see mined that large amounts of breathing air would be required to dilute the CO_2 given off by the plants during the dark cycle. After the chamber became adequately sealed to track CO_2 buildup, it was decided to only add CO_2 as the plants used it.

Original plans to custom mix the atmosphere inside the BPC were put aside due to safety concerns about using pure oxygen. Since then, ambient air has been used in the chamber. Oxygen buildup is slight, since normal work routines do not allow the chamber to be sealed for more than a few days at one time. Currently plans are to add an oxygen concentrator to remove excess oxygen from both chambers of the BPC. This will allow the chamber to be sealed for long durations during a plant experiment.

Carbon dioxide is measured using two infrared gas analyzers (IRGA), one for each level of the BPC. These are used for the control system. There is a third IRGA connected to the monitoring system which automatically samples the upper BPC, lower BPC, hangar air, and outside air. Oxygen is measured using the same two IRGAs (which contain a fuel cell) connected to the control system, and a separate oxygen sensor for the monitoring system. Again, the monitoring system measures the upper BPC, lower BPC, hangar air, and outside air. Automatic calibration is performed on both the control and monitoring analyzers daily, with a complete manual calibration being performed weekly.

Objectives

Tests were conducted to more objectively assess the performance of the BPC. The main goal was to first determine the operating range for critical environmental parameters. This will allow us to better plan future crop and system tests and to anticipate potential problems. During the "downtime" period between crop experiments, the BPC was operated to determine the following:

1) Minimum air temperature attainable
2) Maximum and minimum nutrient temperature attainable
3) Minimum relative humidity attainable
4) Power consumption of lamps for a given output
5) Effect of pressure control system on leakage

These tests were conducted using the standard instrumentation and sensors in the BPC and used during crop experiments. However, there were no crops in the chamber during any of the tests.

imately five hours to traverse the entire temperature range of 27° to 12°C. Turning on the lights raised the nutrient temperature 1°C.

Minimum Relative Humidity - Minimum relative humidity was determined by opening the chilled water coil to 100% and letting the hot water coil try to maintain temperature. Figure 8 shows the results of this test. Chilled water temperature averaged 12°C. Air temperature was set at 22°C, although it never rose to that point after opening the chilled water coil. From the psychrometric chart, the minimum relative humidity attainable should have been around 55-60%, and we reached 65%. During automatic control of humidity, the operating range falls between 70 and 80%. The failure to reach the maximum operating limits is due to the inability to remove condensed water from the coil before it is blown back into the air duct.

Lamp Power Consumption - Two dimming ballasts were tested. Current drawn was measured for a given amount of light output. Figures 9 and 10 show similar shapes, although the absolute numbers are not the same. The curves are typical of the silicon-controlled rectifiers (SCR) used for dimming the bank of lamps. As the lamps are dimmed, the amount of current drawn by the ballast is decreased, until the SCR begins to create a reactive load, then the current increases. This is a typical characteristic of SCRs.

Pressure Control System - The BPC is tested for leakage during non-crop experiments by raising the carbon dioxide level and measuring the decay rate. The leak rate is calculated using the formula described by Sager, et al (1988). Two tests were conducted, one with the pressure control system enabled and the other with the pressure control system disabled. The results in Figures 11 and 12 show that leakage is slightly reduced from over 11% to approximately 10% of the total chamber volume per day.

Summary and Conclusions

The Biomass Production Chamber (BPC) is the major component in the CELSS Breadboard Project. Baseline data was needed to understand the capabilities of the chamber for crop growth experiments. It was also needed in order to measure the effects of current and future modifications. Tests were conducted on the main components of the BPC. Minimum air temperature, minimum and maximum nutrient temperature, minimum relative humidity, chamber leakage, and lighting power consumption were all measured. The chamber behaved as expected, however there remains room for improvement.

Temperature stratification and poor humidity control are both symptoms of the same problem: inadequate monitoring and

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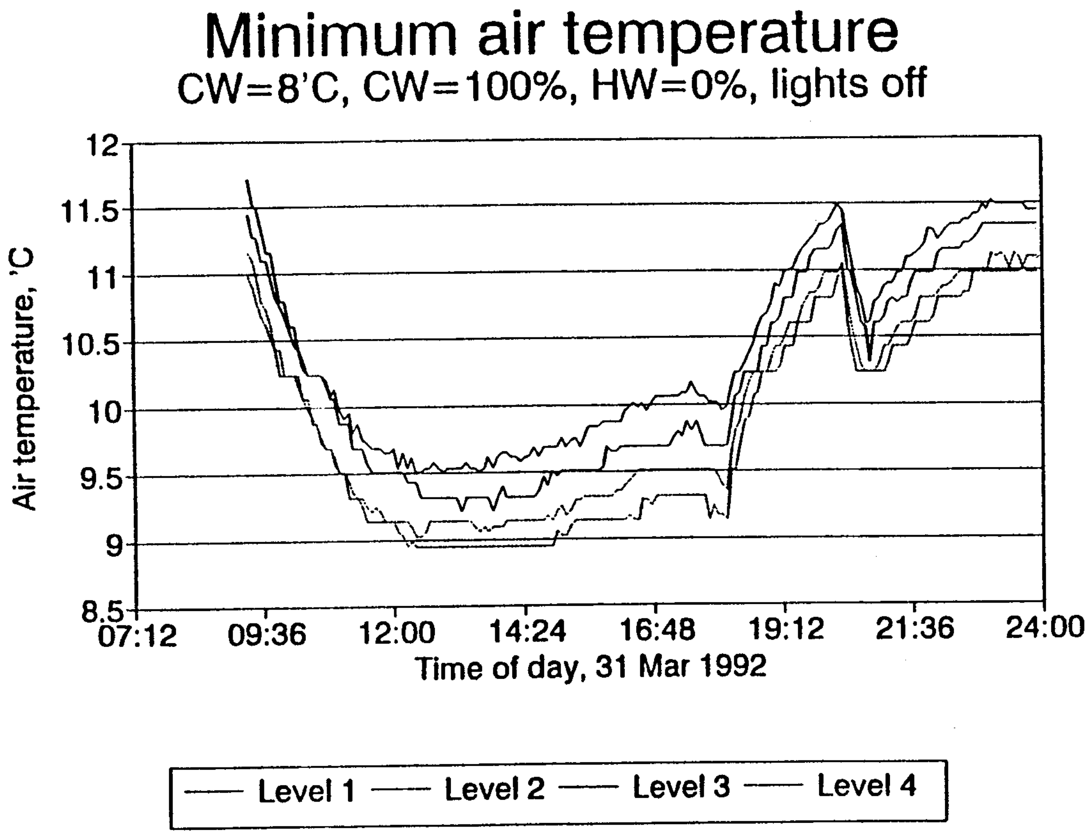

Fig. 2 Minimum air temperature, lights off

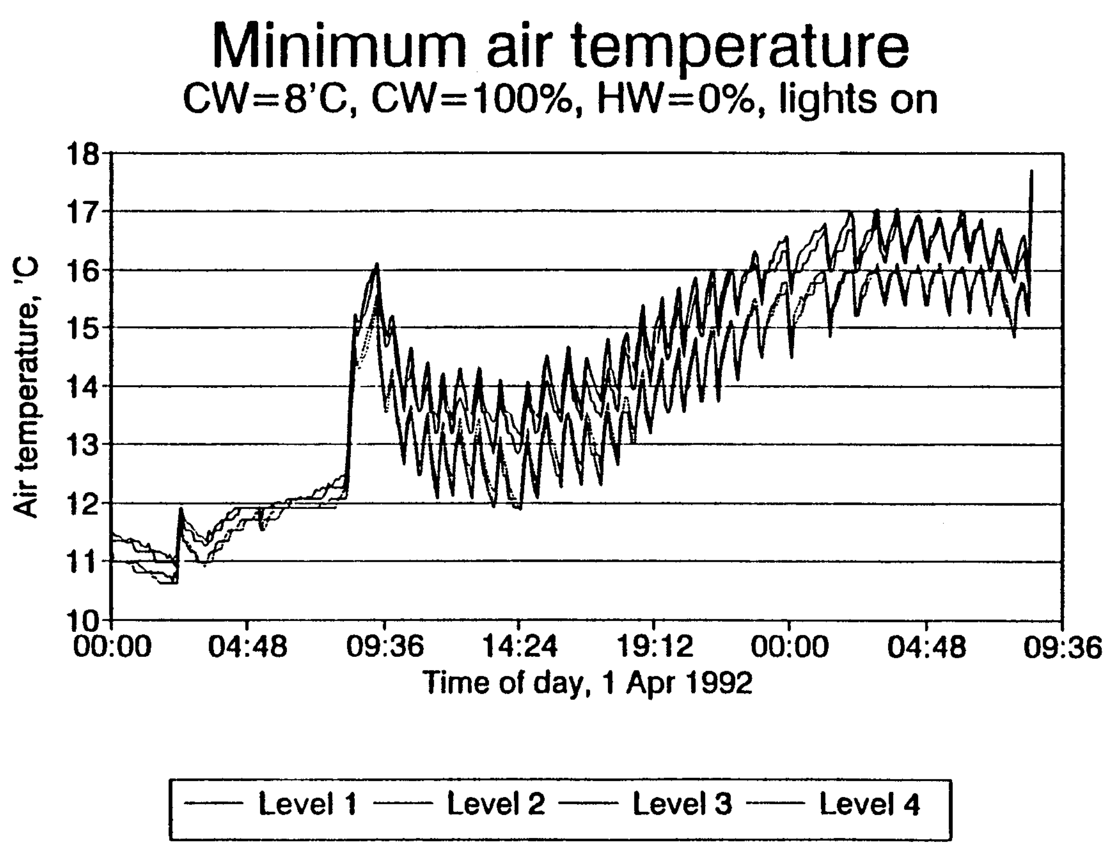

Fig. 3 Minimum air temperature, lights on

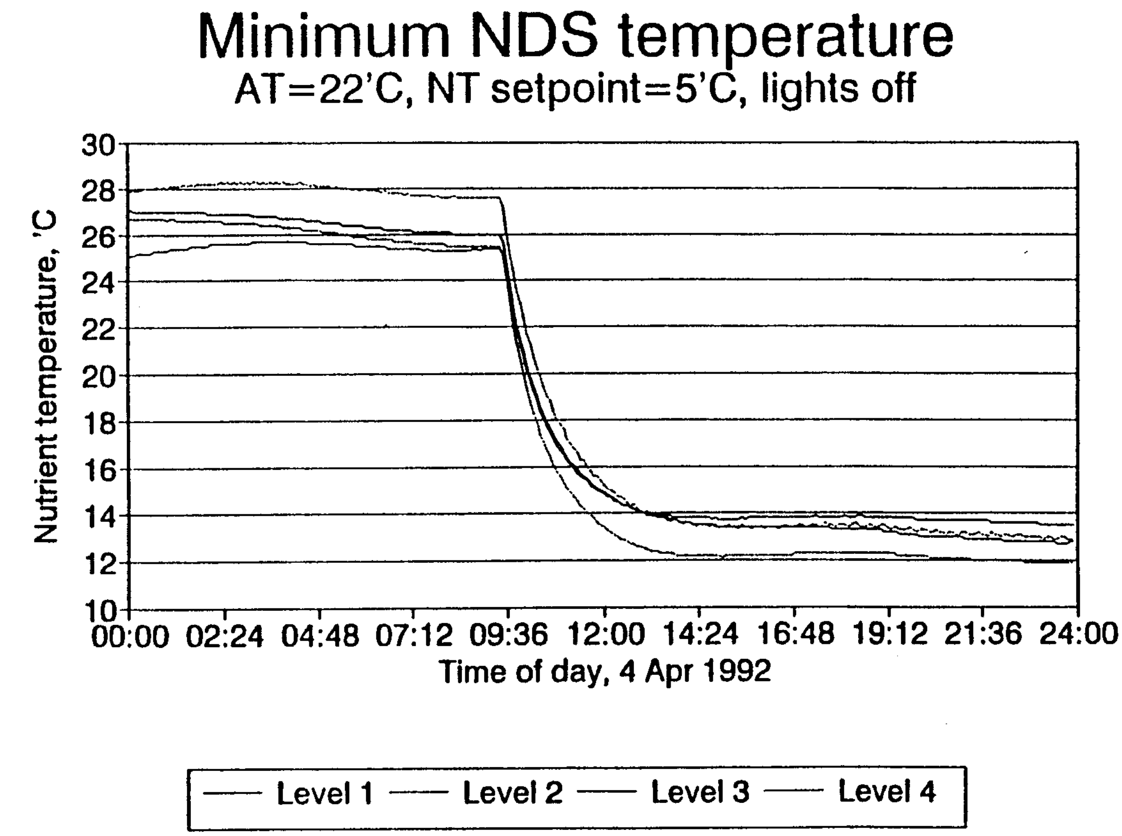

Fig. 6 Minimum nutrient temperature, lights off

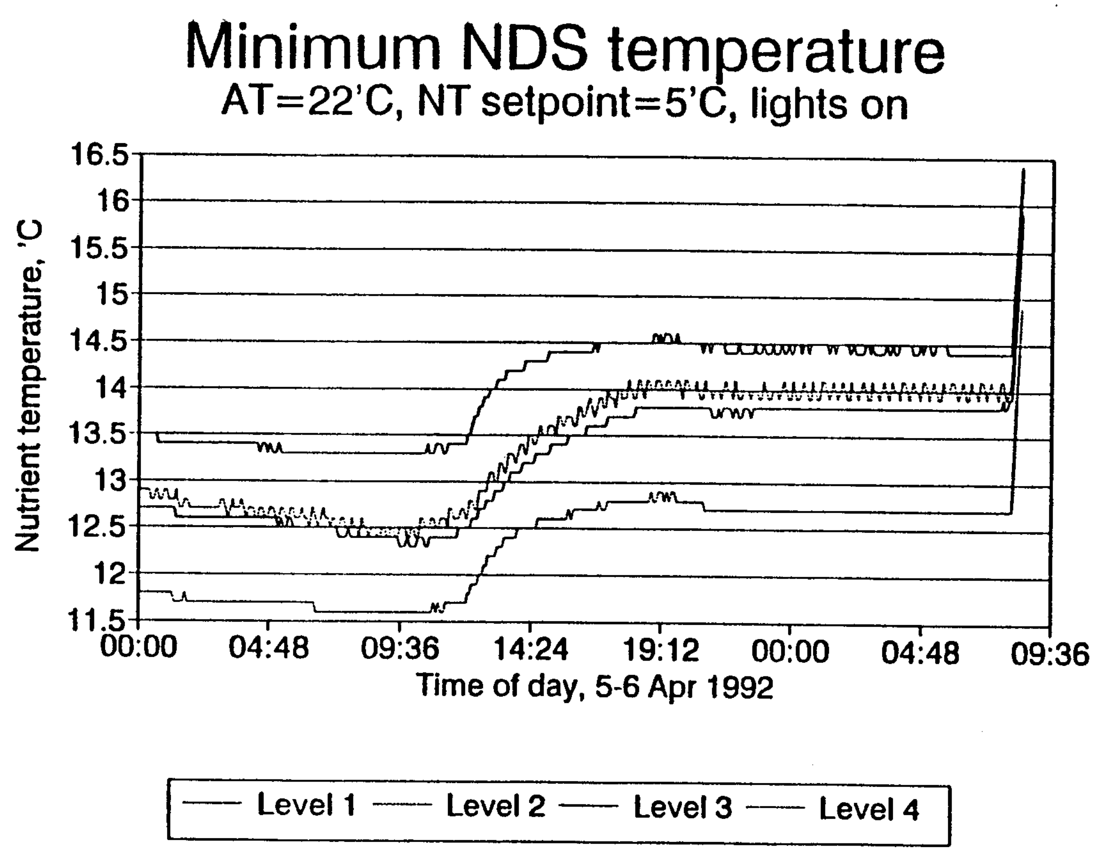

Fig. 7 Minimum nutrient temperature, lights on

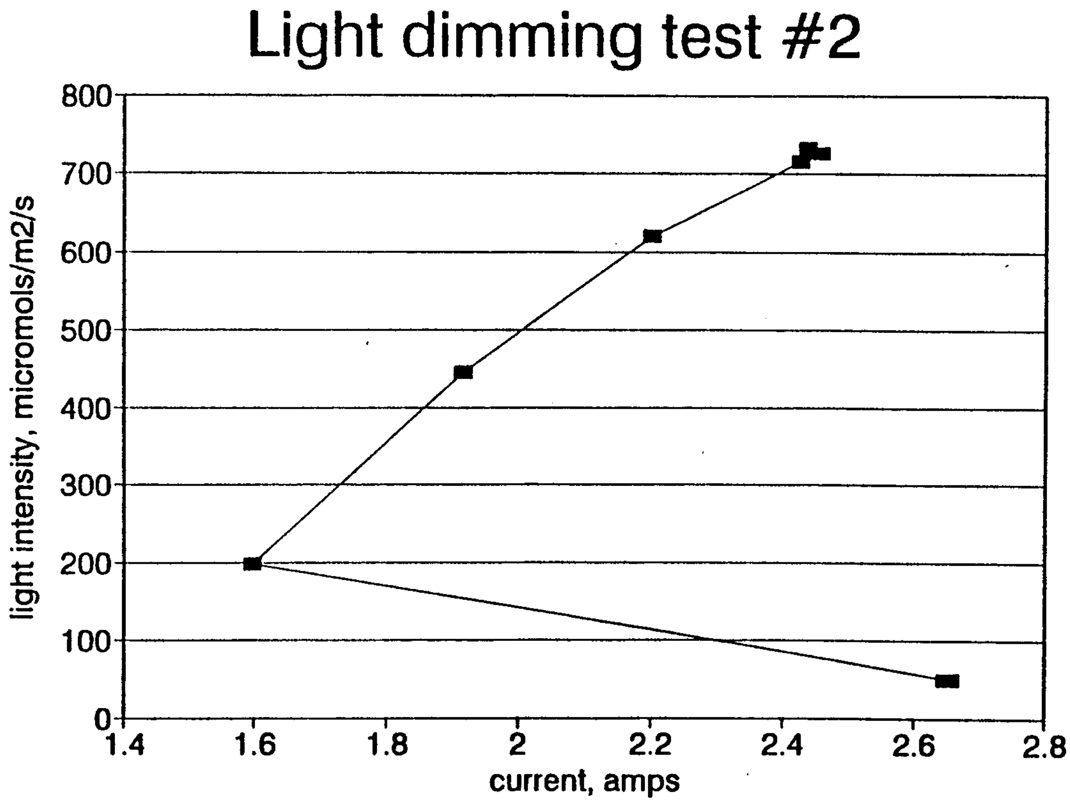

Fig. 10 Current drawn for different lighting intensities

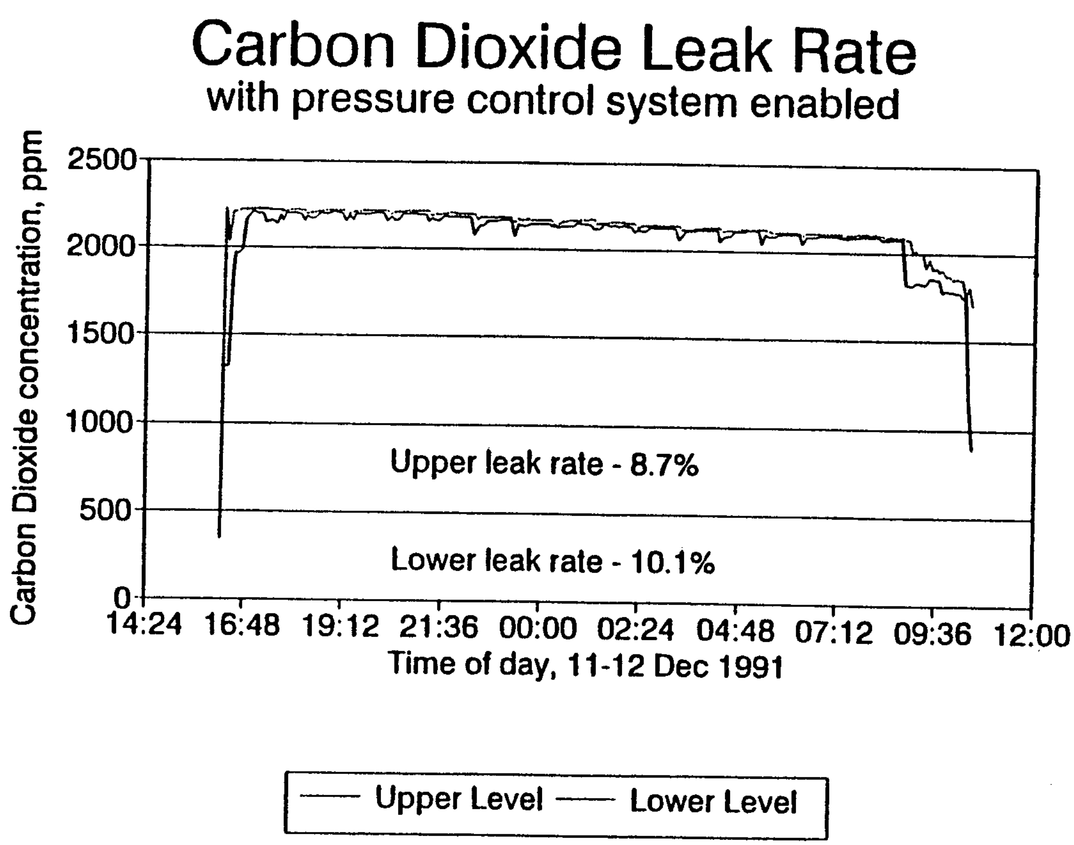

Fig. 11 Chamber leakage with pressure control enabled